Interannual forcing of mesoscale eddy kinetic energy in the subtropical southern Indian Ocean

Andrew Delman (Jet Propulsion Laboratory)

Tong Lee (Jet Propulsion Laboratory)

Bo Qiu (University of Hawai‘i, Mānoa)

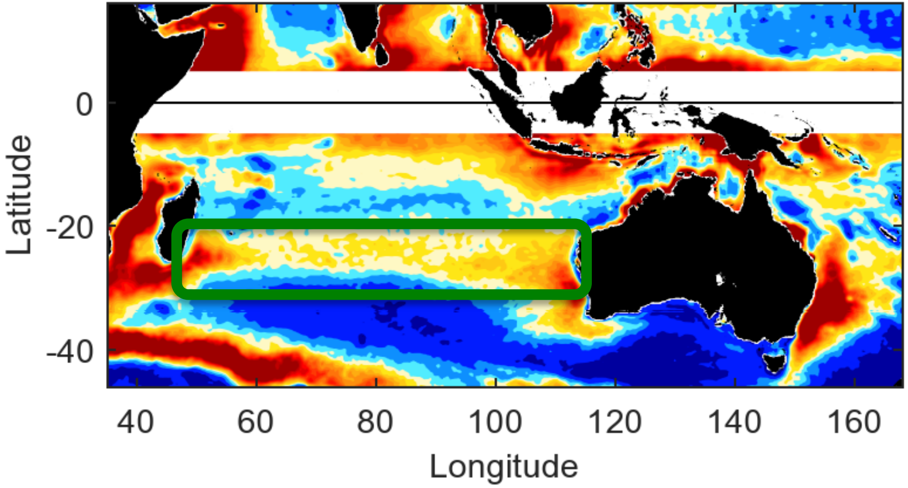


Image: Time-mean surface eddy kinetic energy, from SSALTO/DUACS altimetry product

COSPAR 2018 – 42nd Assembly

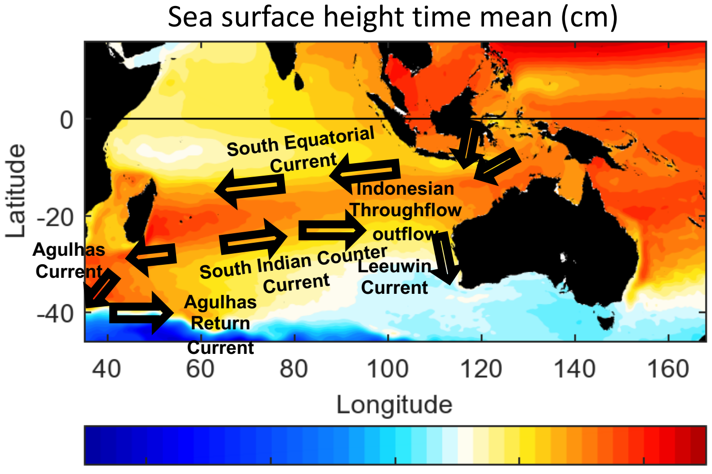
19 July 2018

Jet Propulsion Laboratory
California Institute of Technology

Why study eddies in the subtropical southern Indian Ocean (SSIO)?

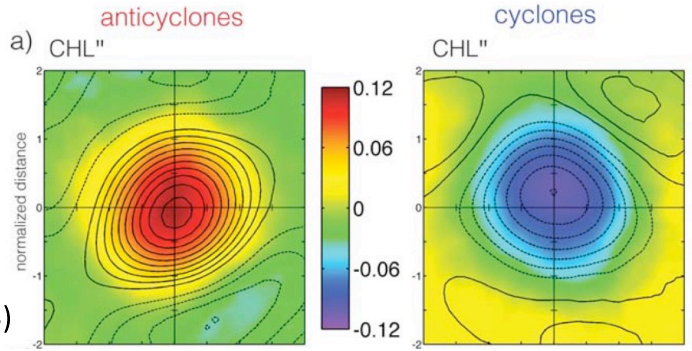
SSIO eddies are not as energetic as eddies in some other areas, however they…

- Are located at the intersection of numerous currents, including an unusual poleward-flowing eastern boundary current (Leeuwin Current)



- Are important for heat transport of the IO shallow overturning circulation (Lee and Marotzke 1998, Schott et al. 2002, Lee 2004), and may interact with the atmospheric boundary layer

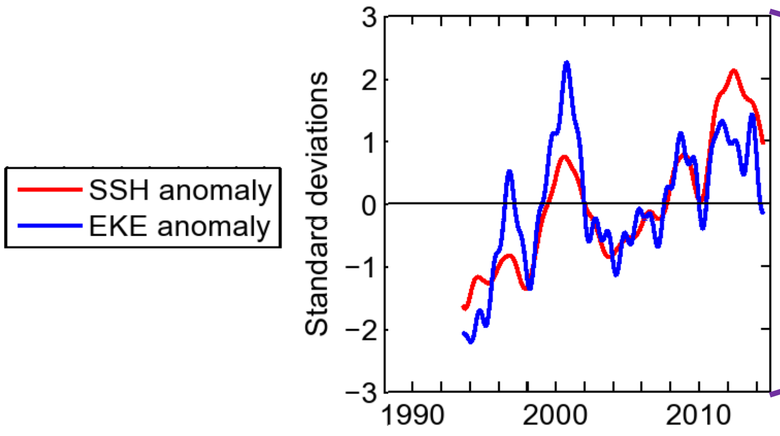
- Have significant impacts on chlorophyll anomalies in the region (Gaube et al. 2013, Gaube et al. 2014)



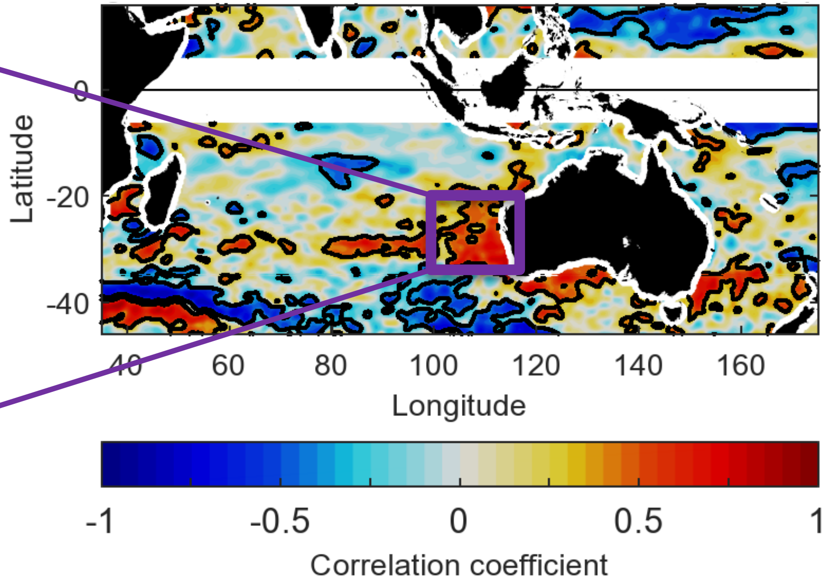
Composite chlorophyll anomalies of SSIO eddies (Gaube et al. 2013)

SSIO sea surface height (SSH) and eddy kinetic energy (EKE) variability

SSH and EKE anomalies from altimetry, averaged in the Leeuwin Current west of Australia



SSH-EKE anomaly correlation (after detrending), 0 lag
Interannual/decadal timescales



- **Why are SSH and EKE anomalies correlated in the eastern SSIO (Leeuwin Current region)?**

Research questions

- **Which mechanism(s) explain the close relationship between SSH and EKE on interannual/decadal timescales in parts of the SSIO?**

…with possible implications for long-term trends in EKE

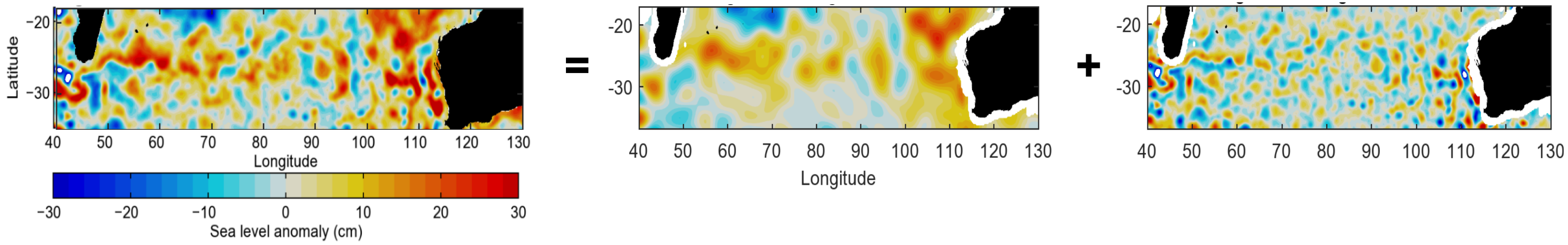
- **Which climate and/or interior ocean forcings control the interannual and decadal variability of EKE in the SSIO?**

…with possible implications for heat/tracer transport variability & predictability

Separation of oceanic motions by spatial scales

In order to focus on dynamics at mesoscales (tens of km to ~200 km)

- Low-pass filter SSH (or SLA, i.e., SSH anomaly) in both longitude and latitude
- Use 6° wavelengths (~670 km) as the cutoff threshold, based on eddy scales in Chelton et al. (2011)



SSALTO/DUACS SLA snapshot 2011 Jul 02

SLA_{lp}

SLA_{meso}

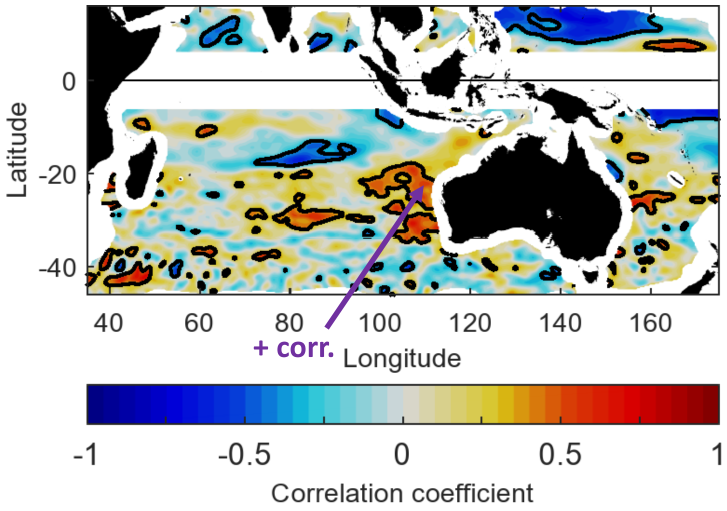
- The low-passed field represents larger-scale motions
- Residual represents mesoscale motions (such as eddies)
- **EKE can be computed from each individual field, e.g.,**

$$\mathrm{EKE}_{\mathrm{meso}} = \frac{1}{2}\left\| \hat{\mathbf{k}} \times \frac{g}{f} \nabla (\mathrm{SLA}_{\mathrm{meso}}) \right\|^2$$

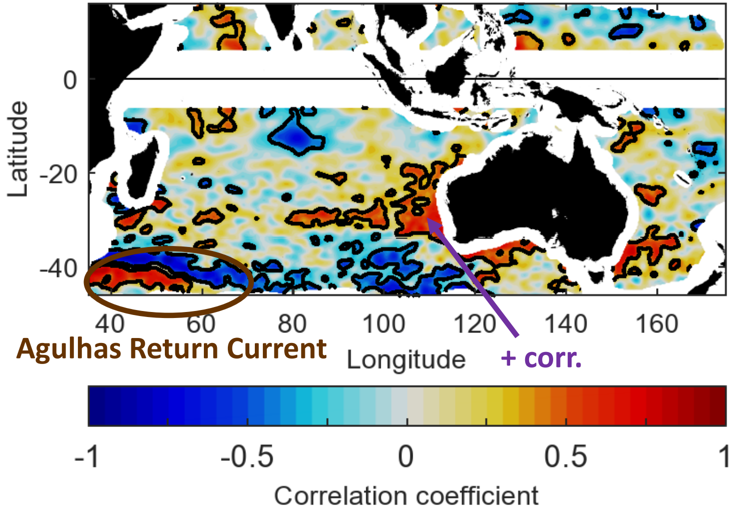
Correlation between SSH and EKE at interannual/decadal timescales

Zero-lag correlation of unfiltered SSH and

Large-scale EKE (EKE_{lp}) – mostly Rossby waves

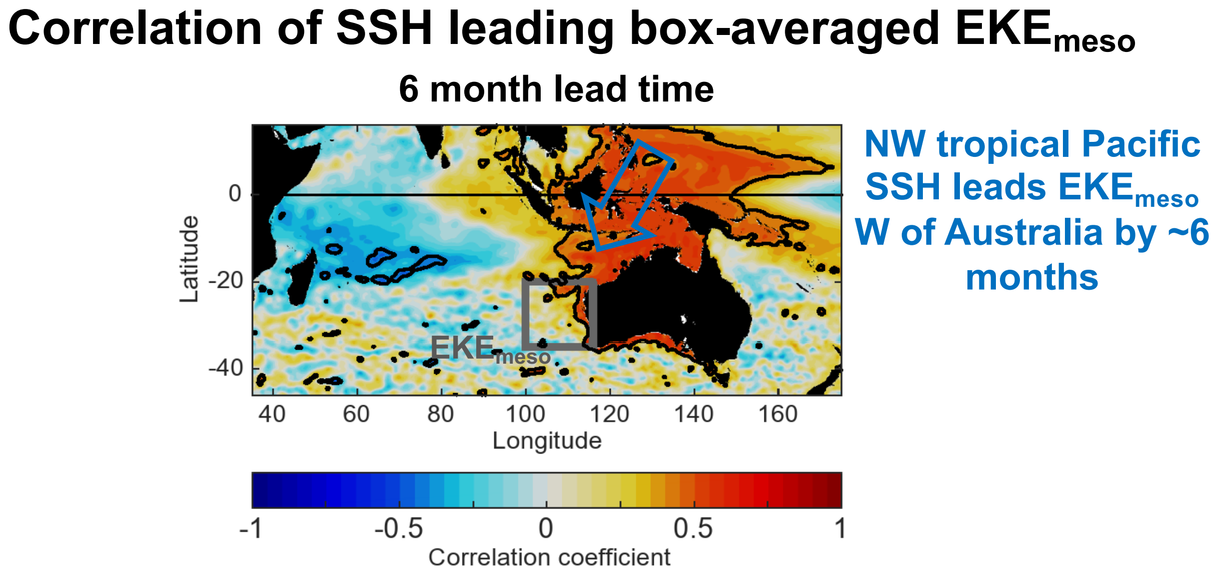


Mesoscale EKE (EKE_{meso}) – mostly eddies



- Robust positive correlation between SSH and EKE at both large scales and mesoscales, **but confined mostly to the eastern part of the SSIO band near the Leeuwin Current**

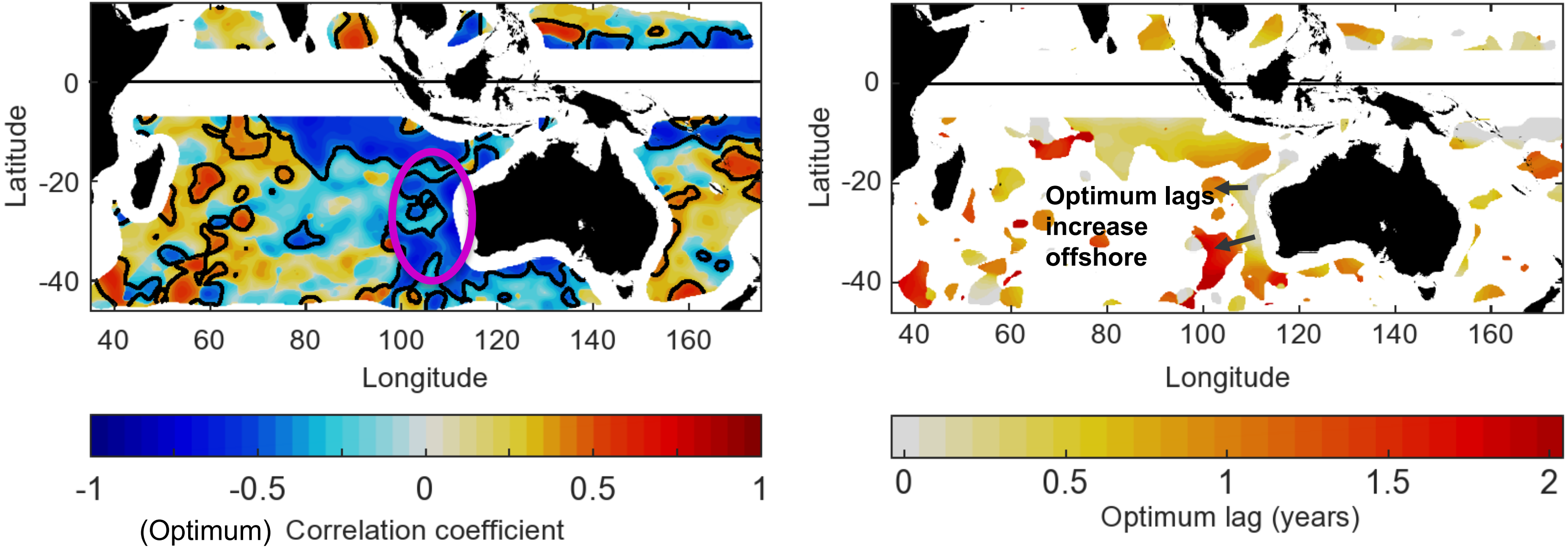
Hypothesis: Pacific forcing influences both SSH and EKE variations, instead of SSH forcing EKE



- Correlation implies that Pacific dynamics are an important influence on SSIO eddy activity
- Any connection with the tropical Pacific also implies a possible connection with ENSO…

Optimum correlations of Niño3.4 index leading mesoscale EKE

- Jia et al. (2011) found a correlation between ENSO and SSIO eddy activity, but did not examine its spatial dependence
- Hence we correlate the Niño3.4 index with the time variation in mesoscale EKE around the region
    - Plot the maximum magnitude correlation coefficient at any lag in a 0-2 year range



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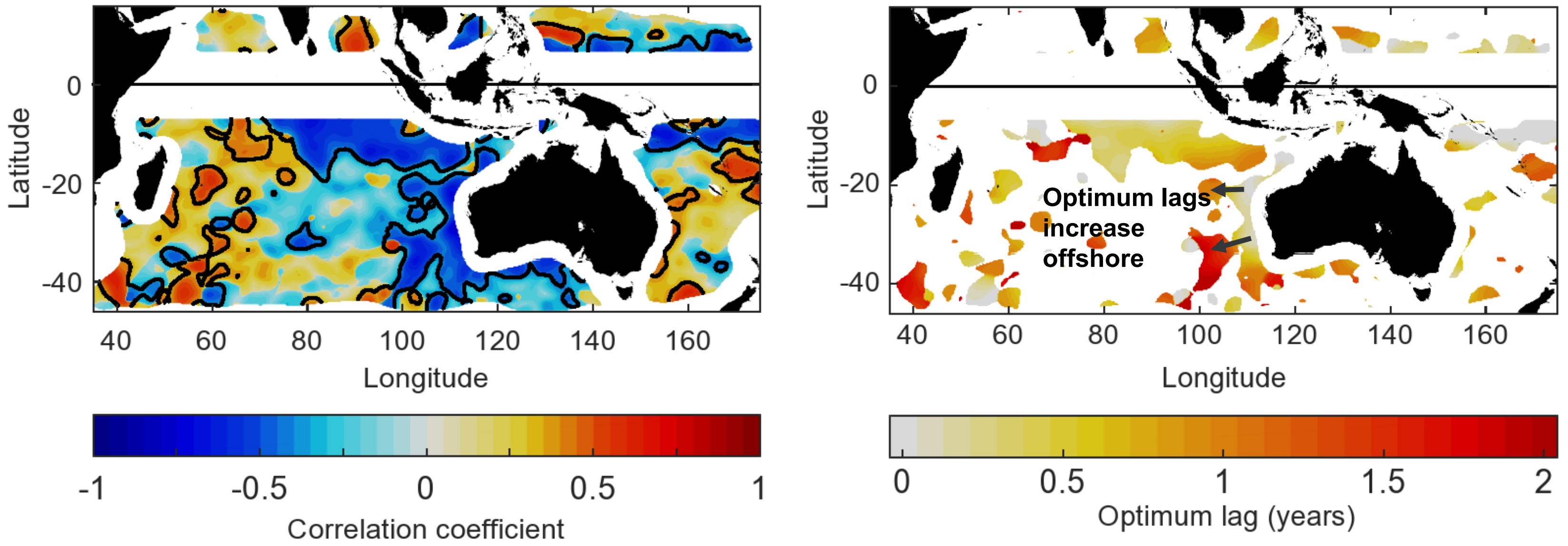
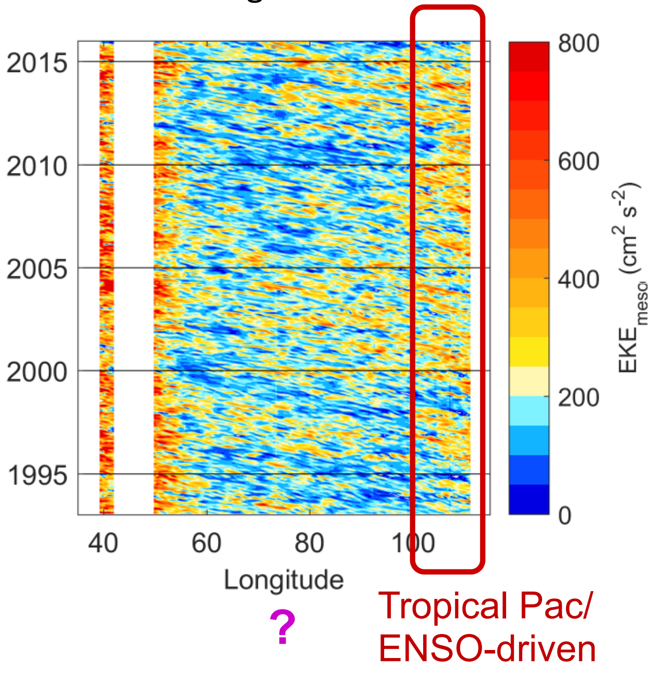


- Results: Optimum correlation is robustly negative east of 100°E; mostly insignificant elsewhere
  - El Niño → lower mesoscale EKE near Australia
  - La Niña → higher mesoscale EKE near Australia

- What drives eddy variability away from the Leeuwin Current (central & western SSIO), in the absence of large-scale climate forcing?

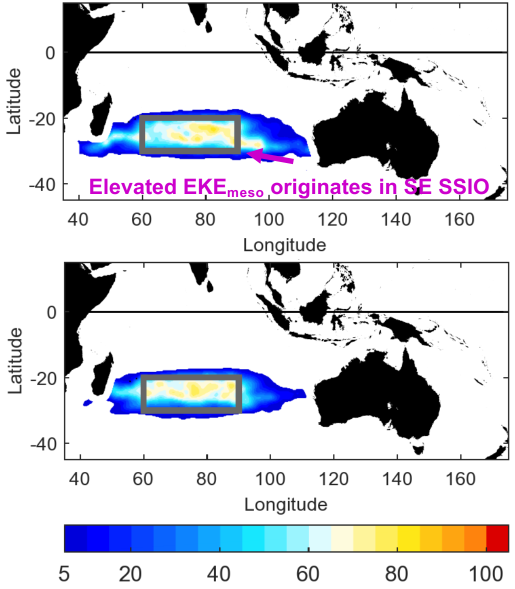
Hovmöller diagram of mesoscale EKE, averaged 25°-20° S



- Using eddy trajectory dataset (developed by Chelton et al., now distributed by AVISO), quantify EKE_{meso} associated with eddy tracks passing through the central/western SSIO

Anticyclonic EKE_{meso} (cm^2 s^{-2})

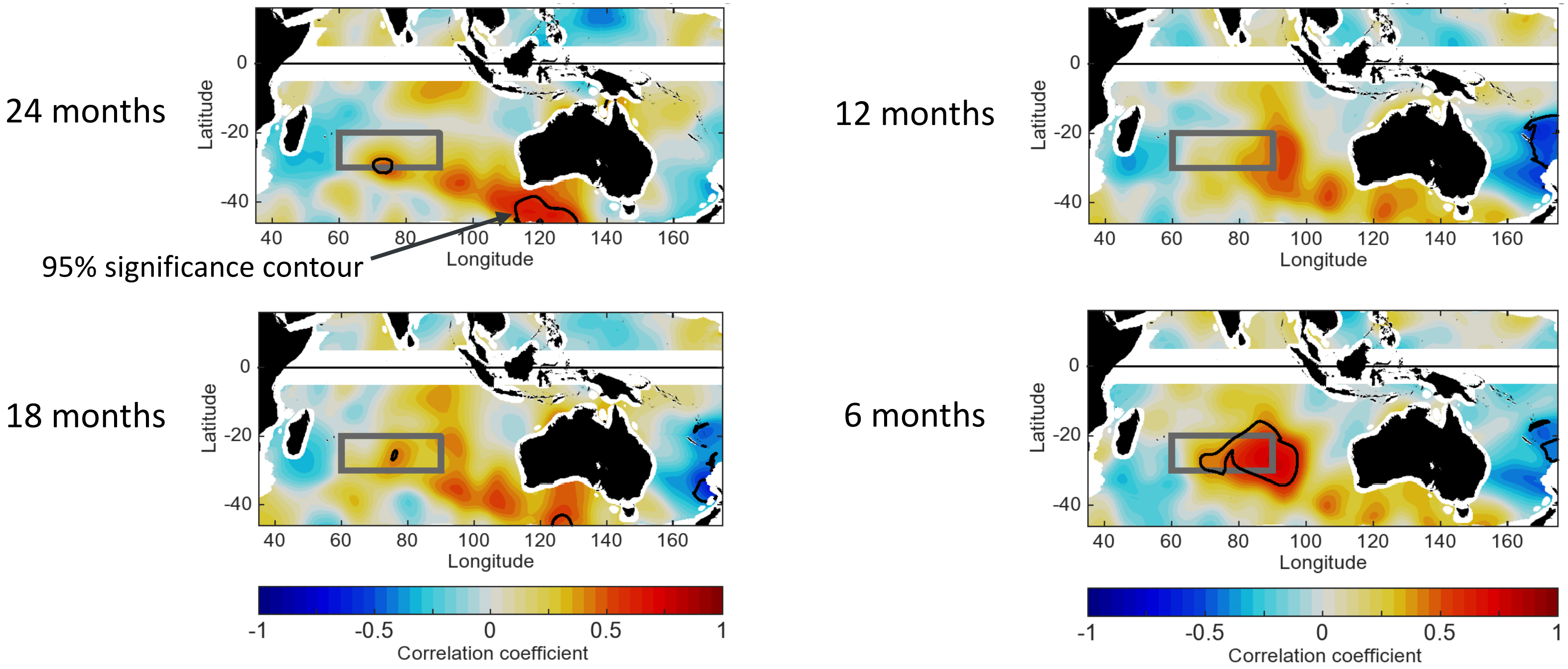
Cyclonic EKE_{meso} (cm^2 s^{-2})



Correlation of regional EKE_{meso} leading EKE_{meso} in the central/western SSIO

- Objective: look to see if temporal variability of mesoscale eddy energy propagates from another region, via an oceanic pathway

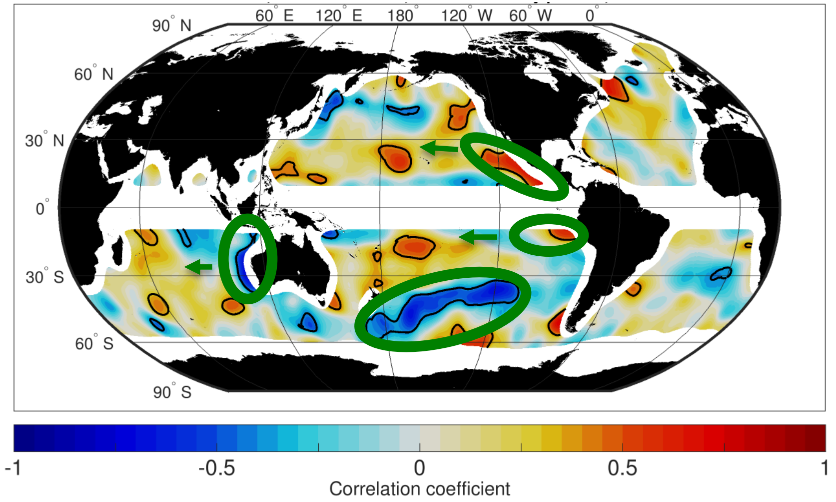
Leading box-averaged central/western SSIO EKE_{meso} by



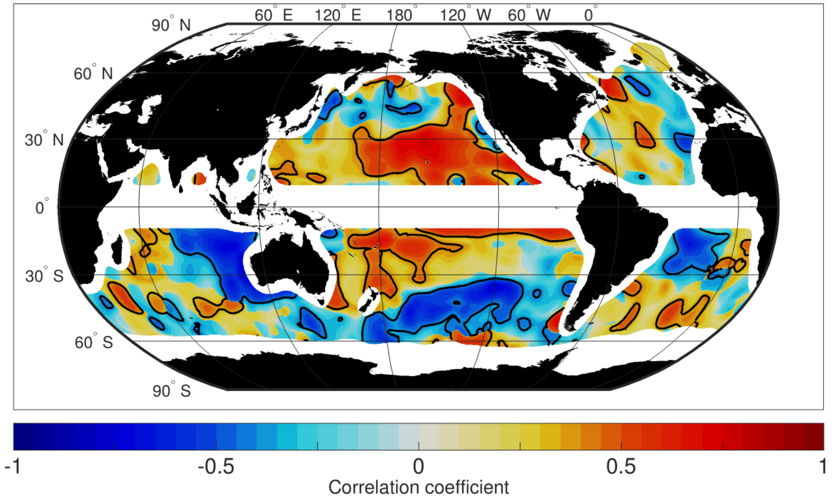
Forcing of EKE interannual variability globally

Niño3.4-EKE interannual/decadal correlation

0 lag

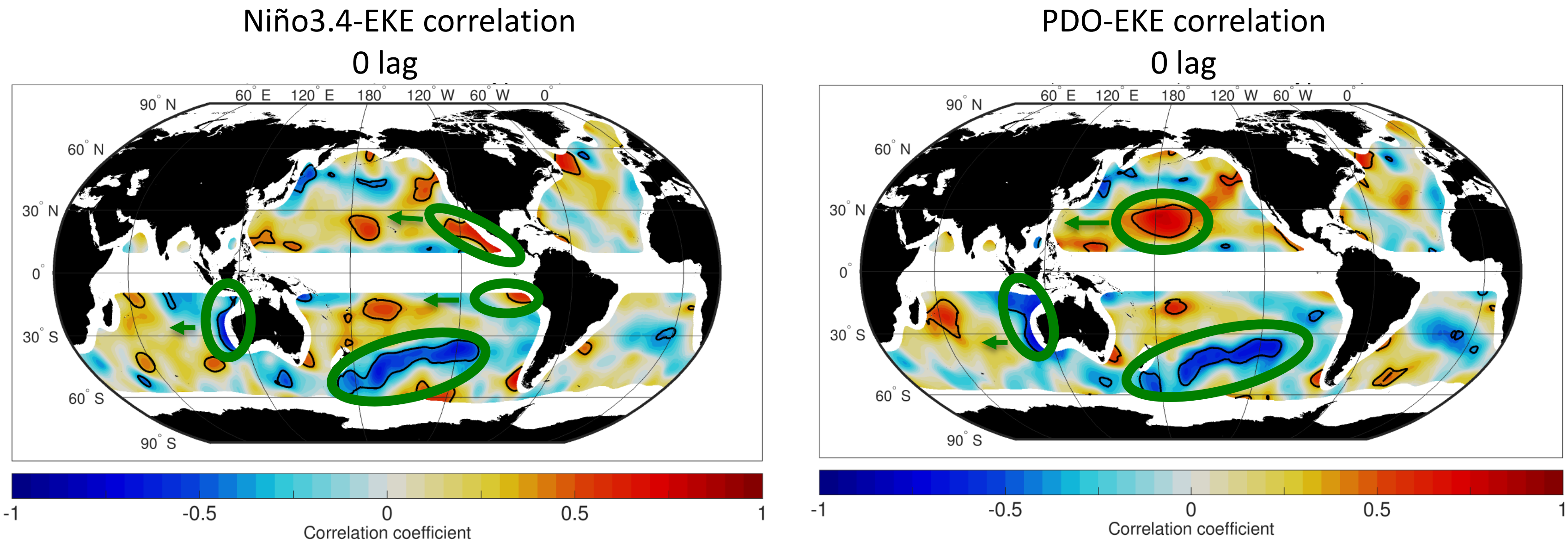


Optimum values: Niño3.4 leads EKE by 0-2 years



- ENSO influences EKE in several regions of the Pacific, as well as in the SSIO
- In the tropical Pacific, this EKE variability propagates westward from the boundary

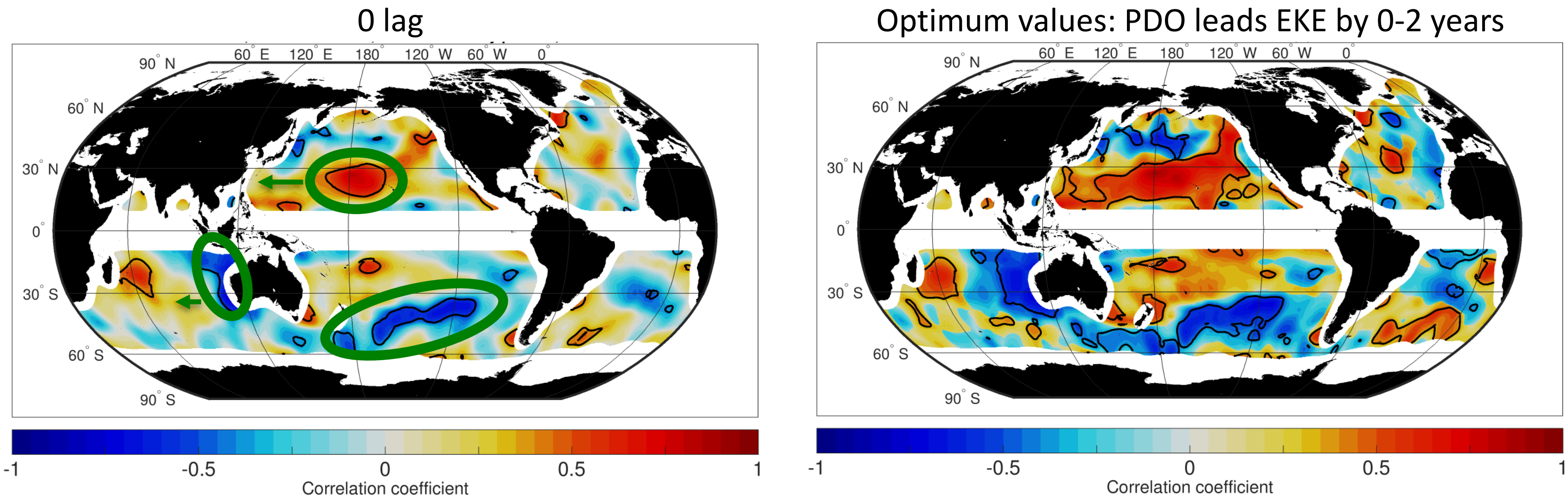
Forcing of EKE interannual/decadal variability globally



- Effect of the Pacific Decadal Oscillation (PDO) on EKE is similar to the effect of ENSO… but more focused on the interior of the ocean

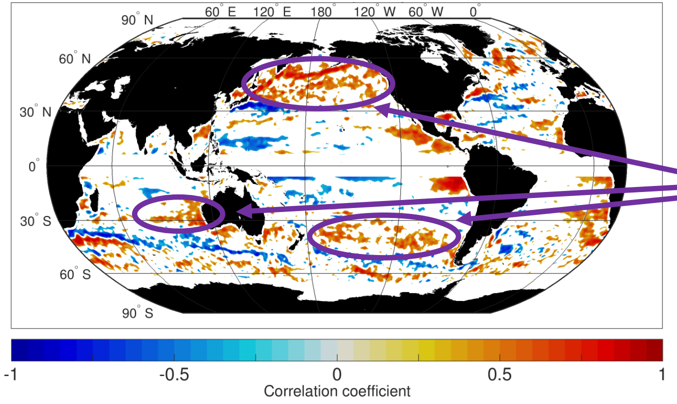
Forcing of EKE decadal variability globally

PDO-EKE interannual/decadal correlation



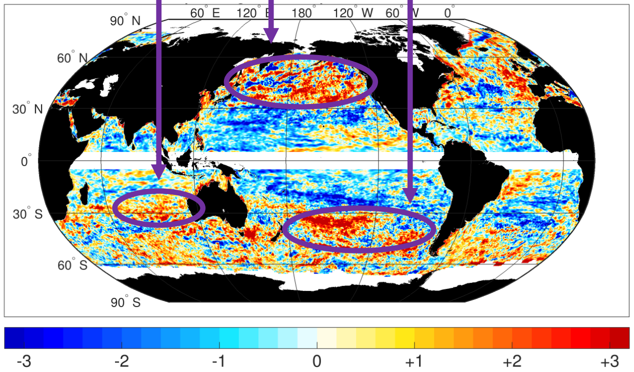
- PDO-related forcing starts in the interior north Pacific, having a greater influence on EKE in the NW Pacific than ENSO forcing

Global SSH-EKE correlation and the EKE trend



SSH-EKE interannual/decadal correlation (detrended), 0 lag

Locations where SSH-EKE correlation and EKE trend are both positive



EKE trend (% yr^{-1}), 1993-2016

- Where the interannual/decadal correlation of SSH and EKE is positive, the secular EKE trend is often positive as well
  - Could understanding the causes of EKE variability in these areas help us understand the trend as well?

Conclusions, and remaining questions

✓ Tropical Pacific sea level and ENSO drive both sea level **and** mesoscale EKE variations in the SSIO near the Australian coast

✓ Data from eddy trajectories show mesoscale EKE originating near 100°E and propagating into the central-west SSIO; most of the remotely-sourced EKE is conveyed by anticyclones (SE → NW)

? Correlation analyses suggest the possibility of mesoscale EKE propagation from much further SE (south of Australia), but do not establish this with 95% confidence

✓ Climate modes (e.g., ENSO, PDO) and variations of SSH are also related to interannual & decadal EKE variability throughout much of the Pacific Ocean

- ? Understanding the forcing mechanisms for this variability may also help us understand the long-term EKE trend

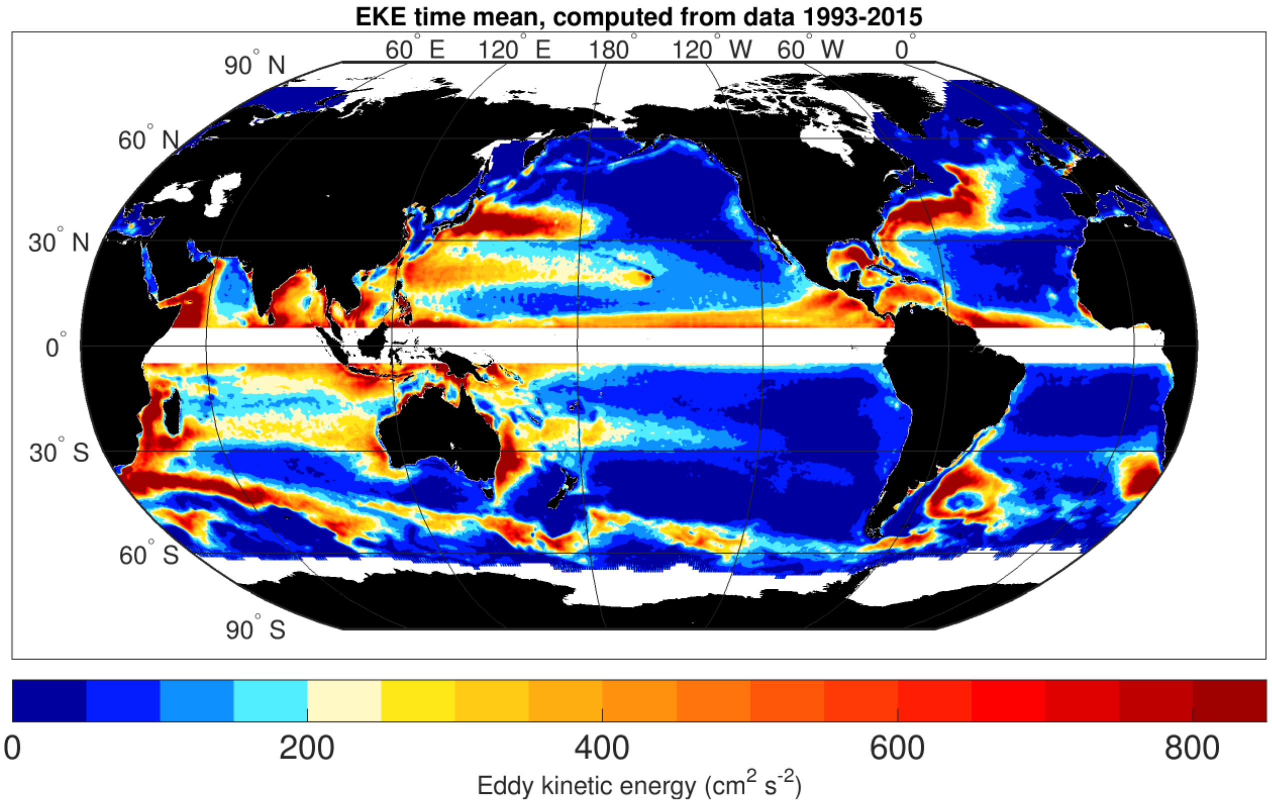
Contact e-mail: Andrew.S.Delman@jpl.nasa.gov

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

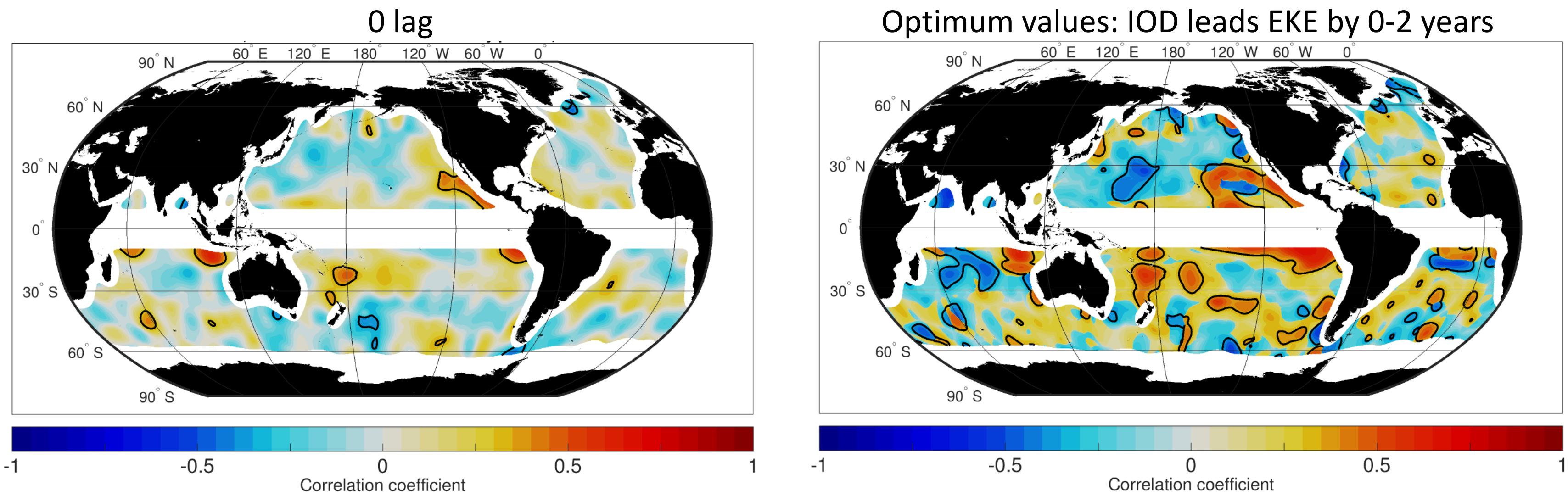
This research was supported by an appointment to the NASA Postdoctoral Program at the Jet Propulsion Laboratory, administered by Universities Space Research Association under contract with NASA.
The authors acknowledge AVISO+, CNES, and Copernicus for providing access to gridded dynamic topography and eddy trajectory data.

EKE time mean



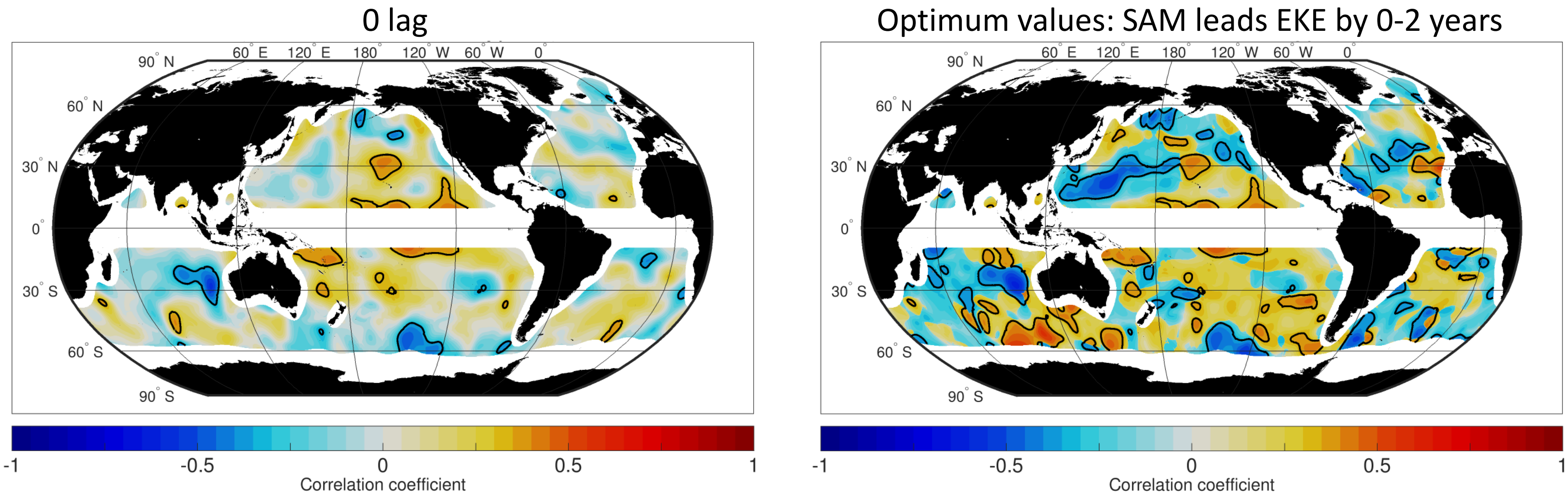
Forcing of EKE interannual variability globally

IOD-EKE interannual/decadal correlation

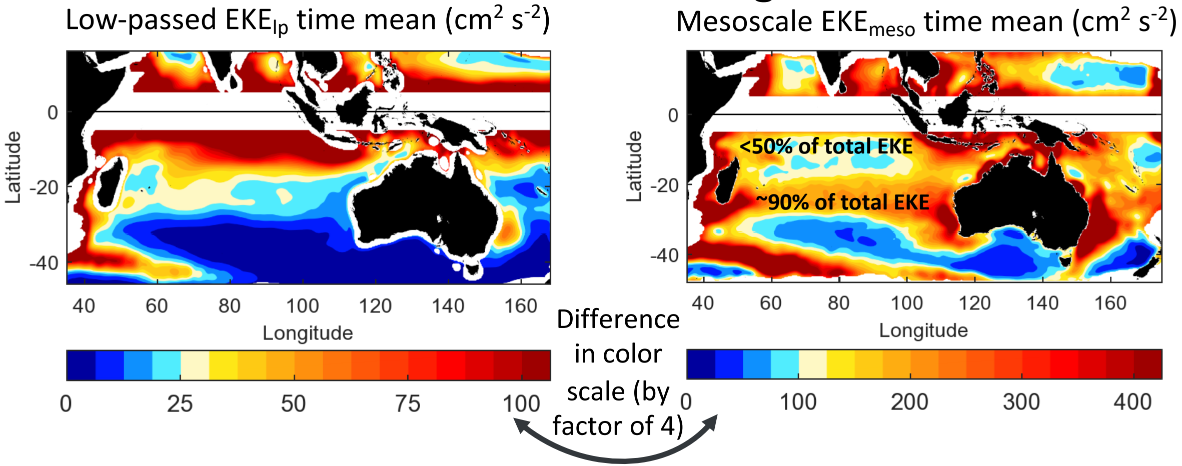


Forcing of EKE interannual variability globally

SAM-EKE interannual/decadal correlation

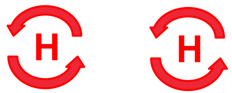


Distribution of EKE associated with large scales and mesoscales

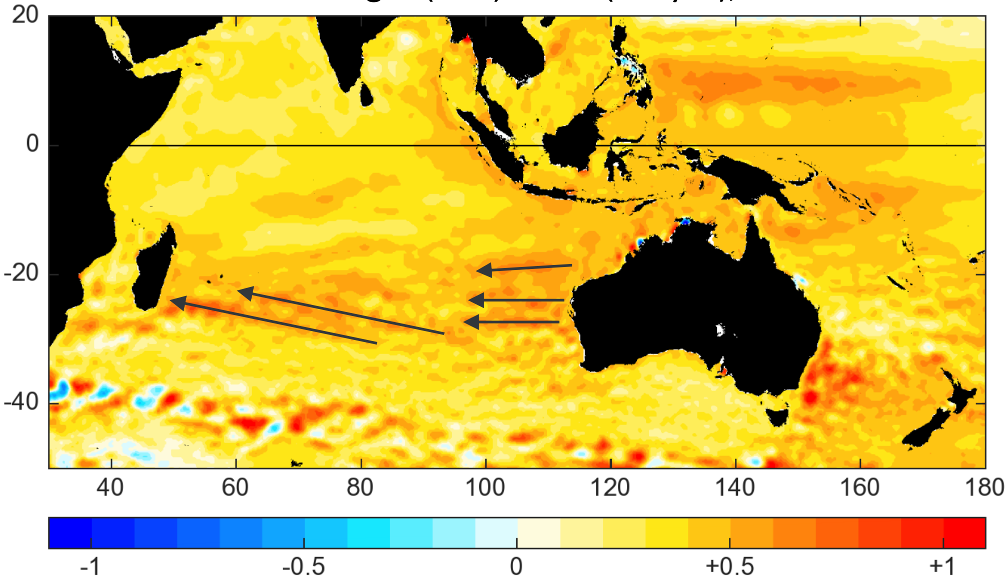


Hypothesis 1: The interannual/decadal variability of EKE in the SSIO is driven by variations in the number of anticyclonic (warm-core) eddies

→ More AC eddies → EKE increases → SSH increases also



Sea surface height (SSH) trend (cm yr^{-1}), 1993-2016



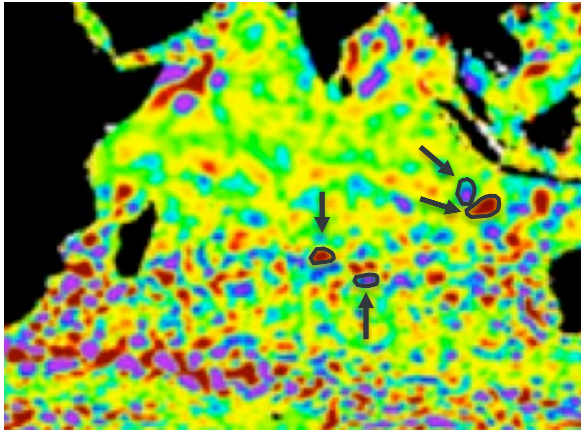
- Highly positive "tracks" in long-term SSH trend look like eddy propagation pathways

Mesoscale eddies and EKE – the eddy counting approach

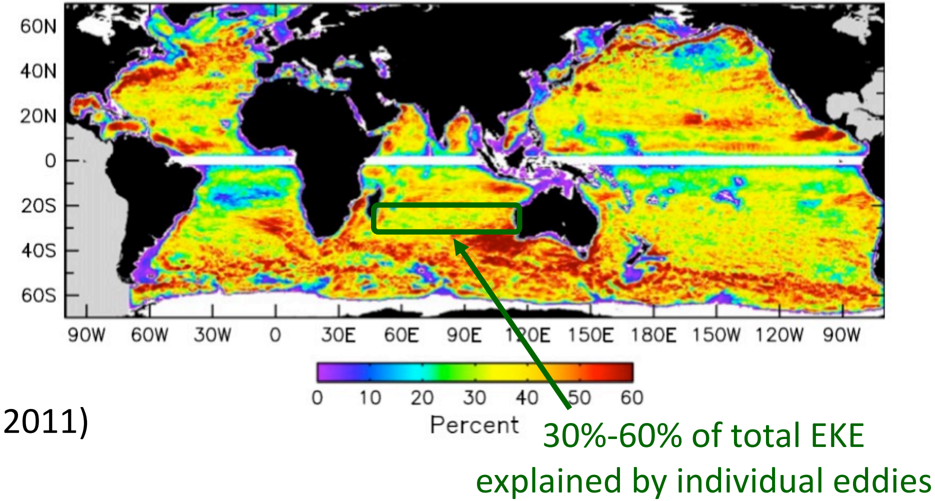
- Isern-Fontanet et al. (2003; 2006), Morrow et al. (2004), and Chelton et al. (2007; 2011) have used algorithms to identify individual mesoscale eddies

- The Chelton et al. (2011) method identifies eddies as closed, compact contours of spatially high-passed sea level anomaly (SSH minus its time mean)

Spatially HP sea level anomaly, 28 Aug. 1996



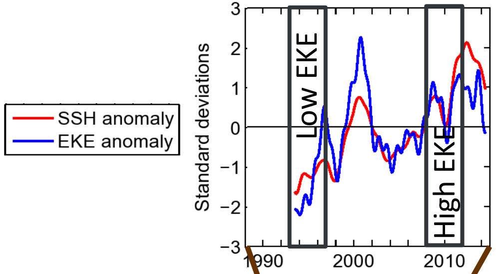
% of total EKE explained by mesoscale eddies (lifetime ≥4 weeks)



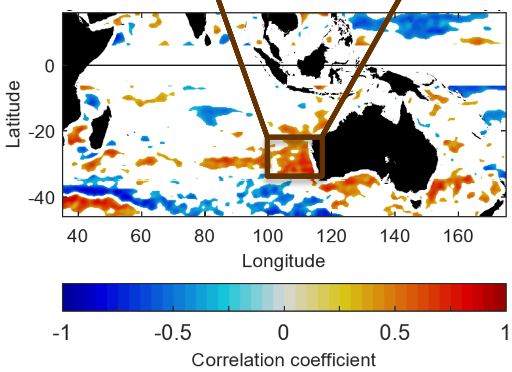
Chelton et al. (2011)

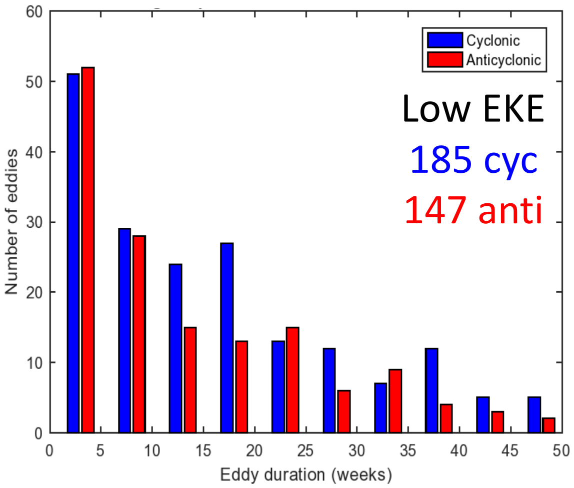
Do anticyclonic eddy variations explain SSH and EKE variability?

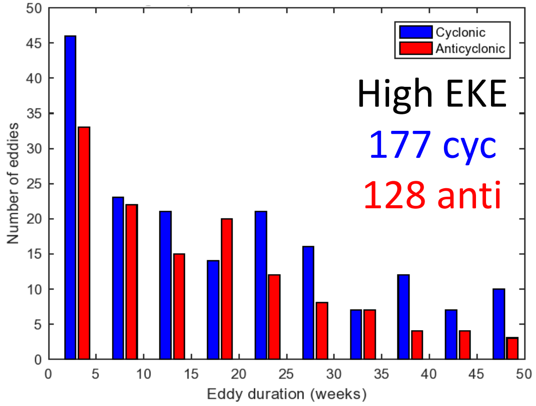
Histograms of cyclonic and anticyclonic eddies identified using the Chelton et al. (2011) method, during low and high EKE periods



SSH-EKE anomaly correlation (after detrending), 0 lag







~~Hypothesis 1:~~

~~More AC eddies → EKE increases → SSH increases also~~

- There are fewer anticyclonic than cyclonic eddies
- Number of AC eddies does not increase during high EKE & SSH periods